

**X. An Account of some Experiments upon coloured Shadows.**  
*By Lieutenant-General Sir Benjamin Thompson, Count of Rumford, F. R. S. In a Letter to Sir Joseph Banks, Bart. P. R. S.*

Read February 20, 1794.

DEAR SIR,

SINCE my last letter, being employed in the prosecution of my experiments upon light, I was struck with a very beautiful, and what to me appeared to be a new appearance. Desirous of comparing the intensity of the light of a clear sky, by day, with that of a common wax candle, I darkened my room, and letting the daylight from the north, coming through a hole near the top of the window-shutter, fall at an angle of about  $70^{\circ}$  upon a sheet of very fine white paper, I placed a burning wax candle in such a position that its rays fell upon the same paper, and as near as I could guess, in the line of reflection of the rays of daylight from without; when interposing a cylinder of wood, about half an inch in diameter, before the centre of the paper, and at the distance of about two inches from its surface, I was much surprised to find that the two shadows projected by the cylinder upon the paper, instead of being merely shades without colour, as I expected, the one of them, that which, corresponding with the beam of daylight, was illuminated by the candle, was *yellow*; while the other,

corresponding to the light of the candle, and consequently illuminated by the light of the heavens, was of the most beautiful *blue* that it is possible to imagine. This appearance, which was not only unexpected, but was really in itself in the highest degree striking and beautiful, I found, upon repeated trials, and after varying the experiment in every way I could think of, to be so perfectly permanent, that it is absolutely impossible to produce two shadows at the same time from the same body, the one answering to a beam of daylight, and the other to the light of a candle or lamp, without these shadows being coloured, the one *yellow* and the other *blue*.

The experiment may very easily be made at any time by day, and almost in any place, and even by a person not in the least degree versed in experimental researches. Nothing more is necessary for that purpose than to take a burning candle into a darkened room in the day time, and open one of the window-shutters a little, about half or three quarters of an inch for instance ; when the candle being placed upon a table or stand, or given to an assistant to hold, in such a situation that the rays from the candle may meet those of daylight from without, at an angle of about  $40^{\circ}$ , at the surface of a sheet of white paper, held in a proper position to receive them, any solid opaque body, a cylinder, or even a finger, held before the paper, at the distance of two or three inches, will project two shadows upon the paper, the one blue, and the other yellow.

If the candle be brought nearer to the paper, the blue shadow will become of a deeper hue, and the yellow shadow will gradually grow fainter ; but if it be removed farther off, the yellow shadow will become of a deeper colour, and the blue shadow will become fainter ; and the candle remaining

stationary in the same place, the same varieties in the strength of the tints of the coloured shadows may be produced merely by opening the window-shutter a little more or less, and rendering the illumination of the paper by the light from without stronger or weaker. By either of these means, the coloured shadows may be made to pass through all the gradations of shade, from the deepest to the lightest, and *vice versa*; and it is not a little amusing to see shadows, thus glowing with all the brilliancy of the purest and most intense prismatic colours, then passing suddenly through all the varieties of shade, preserving in all the most perfect purity of tint, growing stronger and fainter, and vanishing and returning at command.

With respect to the causes of the colours of these shadows, there is no doubt but they arise from the different qualities of the light by which they are illuminated; but how they are produced, does not appear to me so evident. That the shadow corresponding to the beam of daylight, which is illuminated by the yellow light of a candle, should be of a yellowish hue, is not surprising; but why is the shadow corresponding to the light of the candle, and which is illuminated by no other light than the apparently white light of the heavens, *blue*? I at first thought that it might arise from the blueness of the sky; but finding that the broad daylight, reflected from the roof of a neighbouring house covered with the whitest new fallen snow, produced the same blue colour, and if possible of a still more beautiful tint, I was obliged to abandon that opinion.

To ascertain with some degree of precision the real colour of the light emitted by a candle, I placed a lighted wax candle,

well trimmed, in the open air, at mid-day, at a time when the ground was deeply covered with new fallen snow, and the heavens were overspread with white clouds ; when the flame of the candle, far from being white, as it appears to be when viewed by night, was evidently of a very decided yellow colour, not even approaching to whiteness. The flame of an ARGAND's lamp, exposed at the same time in the open air, appeared to be of the same yellow hue. But the most striking manner of shewing the yellow hue of the light emitted by lamps and candles, is by exposing them in the direct rays of a bright meridian sun. In that situation the flame of an ARGAND's lamp, burning with its greatest brilliancy, appears in the form of a dead yellow semi-transparent smoke. How transcendently pure and inconceivably bright the rays of the sun are, when compared to the light of any of our artificial illuminators, may be gathered from the result of this experiment.

It appearing to me very probable, that the difference in the whiteness of the two kinds of light, which were the subjects of the foregoing experiments, might, somehow or other, be the occasion of the different colours of the shadows, I attempted to produce the same effects by employing two artificial lights of different colours ; and in this I succeeded completely.

In a room previously darkened, the light from two burning wax candles being made to fall upon the white paper at a proper angle, in order to form two distinct shadows of the cylinder, these shadows were found not to be in the least coloured ; but upon interposing a pane of yellow glass, approaching to a faint orange colour, before one of the candles,

one of the shadows immediately became *yellow*, and the other *blue*. When two ARGAND's lamps were made use of instead of the candles, the result was the same ; the shadows were constantly and very deeply coloured, the one yellow approaching to orange, and the other blue approaching to green. I imagined that the greenish cast of this blue colour was owing either to the want of whiteness of the one light, or to the orange hue of the other, which it acquired from the glass.

When equal panes of the same yellow glass were interposed before *both* the lights, the white paper took an orange hue, but the shadows were to all appearance without the least tinge of colour ; but *two* panes of the yellow glass being afterwards interposed before one of the lights, while only *one* pane remained before the other, the colours of the shadows immediately returned.

The result of these experiments having confirmed my suspicions, that the colours of the shadows arose from the different degrees of whiteness of the two lights, I now endeavoured, by bringing daylight to be of the same yellow tinge with candle light, by the interposition of sheets of coloured glass, to prevent the shadows being coloured when daylight and candle light were together the subjects of the experiment ; and in this I succeeded. I was even able to reverse the colours of the shadows, by causing the daylight to be of a deeper yellow than the candle light. In the course of these experiments I observed, that different shades of yellow given to the daylight produced very different and often quite unexpected effects : thus one sheet of the yellow glass interposed before the beam of daylight, changed the yellow shadow to a lively violet colour, and the blue shadow to a light green ; two sheets of

the same glass nearly destroyed the colours of both the shadows ; and three sheets changed the shadow which was originally yellow to blue, and that which was blue to a purplish yellow colour.

When the beam of daylight was made to pass through a sheet of blue glass, the colours of the shadows, the yellow as well as the blue, were improved and rendered in the highest degree clear and brilliant ; but when the blue glass was placed before the candle, the colours of the shadows were very much impaired.

In order to see what would be the consequence of rendering the candle light of a still deeper yellow, I interposed before it a sheet of yellow or rather orange-coloured glass, when a very unexpected and most beautiful appearance took place ; the colour of the yellow shadow was changed to orange, the blue shadow remained unchanged, and the whole surface of the paper appeared to be tinged of a most beautiful violet colour, approaching to a light crimson or pink ; almost exactly the same hue as I have often observed the distant snowy mountains and valleys of the Alps to take about sunset. Is it not more than probable that this hue is in both cases produced by nearly the same combinations of coloured light ? in the one case, it is the white snow illuminated at the same time by the purest light of the heavens, and by the deep yellow rays from the west ; and in the other, it is the white paper illuminated by broad daylight, and by the rays from a burning candle, rendered still more yellow by being transmitted through the yellow glass. The beautiful violet colour which spreads itself over the surface of the paper will appear to the greatest advantage, if the pane of orange-coloured glass be held in such

a manner before the candle, that only a part of the paper, half of it for instance, be affected by it, the other half of it remaining white.

To make these experiments with more convenience, the paper, which may be about 8 or 10 inches square, should be pasted or glued down upon a flat piece of board, furnished with a ball and socket upon the hinder side of it, and mounted upon a stand ; and the cylinder should be fastened to a small arm of wood, or of metal, projecting forward from the bottom of the board for that purpose. A small stand, capable of being made higher or lower as the occasion requires, should likewise be provided for supporting the candle ; and if the board with the paper fastened upon it be surrounded with a broad black frame, the experiments will be so much the more striking and beautiful. For still greater convenience, I have added two other stands, for holding the coloured glass through which the light is occasionally made to pass, in its way to the white surface upon which the shadows are projected. It will be hardly necessary to add, that in order to the experiments appearing to the greatest advantage, all light, which is not absolutely necessary to the experiment, must be carefully shut out.

Having fitted up a little apparatus according to the above directions, merely for the purpose of prosecuting these inquiries respecting the coloured shadows, I proceeded to make a great variety of experiments, some with pointed views, and others quite at random, and merely in hopes of making some accidental discovery that might lead to a knowledge of the causes of appearances which still seemed to me to be enveloped in much obscurity and uncertainty.

Having found that the shadows corresponding to two like

wax candles were coloured, the one blue, and the other yellow, by interposing a sheet of yellow glass before one of them ; I now tried what the effect would be when blue glass was made use of instead of yellow, and I found it to be the same ; the shadows were still coloured, the one blue, and the other yellow, with the difference, however, that the colours of the shadows were reversed, that which, with the yellow glass, was before yellow being now blue, and that which was blue being yellow.

I afterwards tried a glass of a bright amethyst colour, and was surprised to find that the shadows still continued to be coloured blue and yellow. The yellow, it is true, had a dirty purple cast ; but the blue, though a little inclining to green, was nevertheless a clean, bright, decided colour.

Having no other coloured glass at hand to push these particular inquiries farther, I now removed the candles, and opening two holes in the upper parts of the window-shutters of two neighbouring windows, I let into the room from above two beams of light from different parts of the heavens, and placing the instrument in such a manner that two distinct shadows were projected by the cylinder upon the paper, I was entertained by a succession of very amusing appearances. The shadows were tinged with an infinite variety of the most unexpected, and often most beautiful colours, which continually varying, sometimes slowly, and sometimes with inconceivable rapidity, absolutely fascinated the eyes, and commanding the most eager attention, afforded an enjoyment as new as it was bewitching. It was a windy day, with flying clouds, and it seemed as if every cloud that passed brought with it another complete succession of varying hues, and most *harmonious* tints. If any colours could be said to predominate it was purples ; but

all the varieties of browns, and almost all the other colours I ever remembered to have seen, appeared in their turns, and there were even colours which seemed to me to be perfectly new.

Reflecting upon the great variety of colours observed in these last experiments, many of which did not appear to have the least relation to the apparent colours of the light by which they were produced, I began to suspect that the colours of the shadows might, in many cases, notwithstanding their apparent brilliancy, be merely an optical deception, owing to contrast, or to some effect of the other neighbouring colours upon the eye. To determine this fact by a direct experiment, I proceeded in the following manner. Having, by making use of a flat ruler instead of the cylinder, contrived to render the shadows much broader, I shut out of the room every ray of daylight, and prepared to make the experiment with two AR-GAND's lamps, well trimmed, and which were both made to burn with the greatest possible brilliancy; and having assured myself that the light they emitted was precisely of the same colour, by the shadows being perfectly colourless which were projected upon the white paper, I directed a tube about 12 inches long, and near an inch in diameter, lined with black paper, against the centre of one of the broad shadows; and looking through this tube with one eye, while the other was closed, I kept my attention fixed upon the shadow, while an assistant repeatedly interposed a sheet of yellow glass before the lamp whose light corresponded to the shadow I observed, and as often removed it. The result of the experiment was very striking, and fully confirmed my suspicions

with respect to the fallacy of many of the appearances in the foregoing experiments. So far from being able to observe any change in the shadow upon which my eye was fixed, I was not able even to tell when the yellow glass was before the lamp, and when it was not; and though the assistant often exclaimed at the striking brilliancy and beauty of the blue colour of the very shadow I was observing, I could not discover in it the least appearance of any colour at all. But as soon as I removed my eye from the tube, and contemplated the shadow with all its neighbouring accompaniments, the other shadows rendered *really* yellow by the effect of the yellow glass, and the white paper which had likewise from the same cause acquired a yellowish hue, the shadow in question appeared to me, as it did to my assistant, of a beautiful blue colour. I afterwards repeated the same experiment with the apparently blue shadow produced in the experiment with daylight and candle-light, and with exactly the same result.

How far these experiments may enable us to account for the apparent blue colour of the sky, and the great variety of colours which frequently adorn the clouds, as also what other useful observations may be drawn from them, I leave to philosophers, opticians, and painters to determine. In the mean time, I believe it is a new discovery, at least it is undoubtedly a very extraordinary fact, that the eyes are not always to be believed, *even with respect to the presence or absence of colours.*

I cannot finish this letter without mentioning one circumstance, which struck me very forcibly in all these experiments upon coloured shadows, and that is, the most perfect harmony

which always appeared to subsist between the colours, whatever they were, of the two shadows ; and this harmony seemed to me to be full as perfect and pleasing when the shadows were of different tints of brown, as when one of them was blue and the other yellow. In short, the harmony of these colours was in all cases not only very striking, but the appearances were altogether quite enchanting ; and I never found any body to whom I showed these experiments whose eyes were not fascinated with their bewitching beauties. It is, however, more than probable, that a great part of the pleasure which these experiments afforded to the spectators arose from the continual changes of colour, tint, and shade, with which the eye was amused, and the attention kept awake. We are used to seeing colours fixed and unalterable, hard as the solid bodies from which they come, and just as motionless, consequently dead, uninteresting, and tiresome to the eye ; but in these experiments all is motion, life, and beauty.

It appears to me very probable, that a further prosecution of these experiments upon coloured shadows may not only lead to a knowledge of the real nature of the harmony of colours, or the peculiar circumstances upon which that harmony depends ; but that it may also enable us to construct instruments for producing that harmony, for the entertainment of the eyes, in a manner similar to that in which the ears are entertained by musical sounds. I know that attempts have already been made for that purpose ; but when I consider the means employed, I am not surprised that they did not succeed. Where the flowing tide, the varying swell, the *crescendo* is wanting, colours must ever remain hard, cold, and inanimate masses.

I am very sorry that my more serious occupations do not at present permit me to pursue these most entertaining inquiries. Perhaps at some future period I may find leisure to resume them.

Munich,  
1st March, 1793.

I am, &c.